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QUARTERLY LITERATURE REVIEW

OF

HYDROGEN ENERGY

A BIBLIOGRAPHY WITH ABSTRACTS

FIRST QUARTER 1977

a product of

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ALBUQUERQUE, NEW MEXICO

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PREFACE

HYDROGEN ENERGY is a continuing bibliographic summary with abstracts of research and projections on the subject of hydrogen as a secondary fuel and as an energy carrier. The first volume was published in January, 1974 and is cumulative through December of 1973. Additional copies are available from the Technology Application Center, as are the quarterly update series for 1974, 1975 and 1976.

This update to HYDROGEN ENERGY cites additional references identified during the first quarter of 1977. It is the first in a 1977 quarterly series intended to provide "current awareness" to those interested in hydrogen energy.

For the reader's convenience, a series of cross indexes are included which track directly with those of the cumulative volume. See "Guide to Use of the Publication."

A library containing some of the articles and publications referenced in this update and the cumulative volume has been established, and the Center will, on a cost-recovery basis, aid readers to obtain copies of any cited material. Although a considerable effort has been made to insure that the bibliography is complete, readers are encouraged to bring any omissions to the attention of this Center.

The Technology Application Center is one of six Industrial Application Centers established by NASA's Technology Utilization Program to evaluate and disseminate new technology to the general public and commercial business.

INTRODUCTION

We note with interest some trends in the hydrogen energy field. The first trend concerns the basic source that supplies energy for water decomposition. Increasing numbers of researchers are investigating the possibility of using alternate energy sources such as solar energy, wind energy, ocean thermal gradients, etc., rather than relying on either conventional fuels or nuclear energy for hydrogen production. Hydrogen or ammonia (derived from it) are envisioned for storage of the diffuse, intermittent forms of renewable energy.

A second trend indicating a certain "maturity" of the field is apparent in the publications area. No longer is the literature found in random, peripheral publications (although some of it certainly is). The majority of papers and studies in the hydrogen energy field are appearing in either the "International Journal of Hydrogen Energy" (Pergamon Press) or in hard cover form. Two publications in the latter form are of important note: (1) The interesting book titled: "Energy, The Solar - Hydrogen Alternative" authored by Professor J. O'M. Bockris (Wiley, 1975) that details in great measure some of the author's futuristic thinking regarding the world, its energy problems and proposing solar - water electrolysis technology as the cure, and (2) the CRC (Chemical Rubber Company) Uniscience Series titled: "Hydrogen, Its Technology and Implication" edited by this editor (K. E. Cox) together with Dr. Kenneth D. Williamson of the Los Alamos Scientific Laboratory. The latter set of five volumes covers all facets of Hydrogen Energy, i.e. Production, Transmission and Storage, Properties, Use and Implications. At this time, Volume III, Properties, is available with the other volumes following shortly.

Together with these trends, we note a diminishing in the "protagonist" papers advocating the advantages of hydrogen, indeed, most of the literature is concerned with serious reporting of work accomplishments verifying the assumptions of the past. The papers are being held for publications at regular forums such as the Miami Hydrogen Conferences indicating a lack of relevant literature in the interim.

We urge the readers of the publication to either send us results of their work or of work they know about that may have escaped our search for future inclusion in the document.

The Editors

Dr. Kenneth E. Cox
Professor, Chemical & Nuclear
Engineering Department

Dr. Mani Natarajan
Technolgoy Application Center

GUIDE TO USE OF THIS PUBLICATION

A number of features have been incorporated to help the reader use this document. They consist of:

-- A TABLE OF CONTENTS listing general categories of subject content and indexes. More specific coverage by subject keyword, title, author, or corporate source is available through the appropriate index.

-- CITATION NUMBERS assigned to each reference. These numbers, with the prefix omitted, are used instead of page numbers to identify references in the various indexes. They are also used as TAC identifier numbers when dealing with document orders so please use the entire (prefix included) citation number when corresponding with TAC regarding a reference. An open ended numbering system facilitates easy incorporation of subsequent updates into the organization of the material. In this system, numbers assigned to new citations in each category will follow directly the last assigned numbers in the previous publication. The citation number of the last reference on each page appears on the upper right-hand corner of that page to facilitate quick location of a specific item.

-- DIVIDER PAGES at the beginning of each major sections containing the section number and title. When a subsection has no citations for that particular update, a divider page with the subsection number and the notice "No Citations in This Category" is inserted where that subsection would normally appear.

-- A REFERENCE FORMAT containing the TAC citation number, title of reference, author, corporate affiliation, reference source, contract or grant number, abstract, and keywords. The reference source tells, to the best of our knowledge, where the reference came from. If from a periodical, the reference source contains the periodical's title, volume number, page number, and date. If for a report, the reference source contains the report number assigned by the issuing agency, number of pages, and date.

--An INDEX OF AUTHORS alphabetized by author's last name. A reference's author is followed by the reference's citation number. For multiple authors, each author is listed in the index.

--An INDEX OF PERMUTED TITLES/KEYWORDS affords access through major words in the title and through an assigned set of keywords for each citation. A reference's title is followed by the reference's citation number. In the indexes, all the words pertaining to a reference are permuted alphabetically. Thus, the citation number for a reference appears as many times as there are major title words or keywords for that reference. The permuted words run down the center of an index page. The rest of the title or keywords appear adjacent to a permuted word. Since a title or set of keywords is allowed only one line per permuted word the beginning, the end, or both ends of a title or set of keywords may be cut off; or, if space permits, it will be continued at the opposite side of the page until it runs back into itself. A # indicates the end of a title or set of keywords while a / indicates where a title or set of keywords has been cut off within a line.

CONTENTS

CONTENTS (continued)

I. GENERAL: CONCEPTS, CONFERENCES, SURVEYS, REVIEWS

H77 10270 HYDROGEN, ITS TECHNOLOGY AND IMPLICATIONS; HYDROGEN PROPERTIES VOLUME III

McCarty, R.D., (National Bureau of Standards, U.S. Department of Commerce, Boulder, CO), Cox, K.E., ed., (University of New Mexico, Albuquerque, NM), Williamson, K.D., (Los Alamos Scientific Laboratory, Los Alamos, NM), CRC Press, Inc., Cleveland, OH, 1975

An important part of any treatise on a subject such as hydrogen is its thermophysical properties. To a large extent, these determine how hydrogen can be stored, transmitted, and then utilized as a secondary energy source, and energy storage system, or a building block for more complex molecules. The National Bureau of Standards, Cryogenics Laboratory in Boulder, Colorado, has played a leading role in experimental programs to obtain hydrogen properties. The Cryogenic Data Center has been collecting data and documents pertinent to the field for over 15 years. The basis of Volume III in the CRC "Hydrogen, Its Technology and Implications" edited by Cox and Williamson is Robert D. McCarty's "Hydrogen Technological Survey - Thermophysical Properties" issued in 1975 as NASA Report SP-3089. This publication was part of a major hydrogen safety review by the NASA Aerospace Safety and Data Institute (ASRDI). The volume gathers together all the available thermophysical properties of hydrogen in tabular or graphical form. A comprehensive list of 287 original references are provided for those who need to pursue the field in greater depth.

(PROPERTY, THERMOPHYSICAL)

H77 10271 INTERNATIONAL COOPERATION ON DEVELOPMENT OF HYDROGEN TECHNOLOGIES

Vanderryn, J., (U.S. ERDA, Washington, DC), Salzano, F.J., (Brookhaven National Laboratory, Upton, L.I., NY), Bowman, M.G., (Los Alamos Scientific Laboratory, Los Alamos, NM), International Journal of Hydrogen Energy, V 1:357-363, N4, 1977

The production transmission and utilization of hydrogen has been identified as one of the priority areas for international cooperation under the International Energy Agency. Two coordinating committees and two working panels have been organized to coordinate cooperative activities in the fields of water electrolysis, thermochemical water splitting, the interfacing of nuclear reactors with production processes and the general area of systems studies and assessment of a developing hydrogen technology. Meetings of these groups have been held with participating experts from interested countries. From these developments it is quite clear that the cooperative programs under the IEA will lead to improved R & D Programs. One goal of the cooperation is joint participation of the member countries in the large and expensive commercial demonstration of the developing new technology.

(TRANSMISSION, UTILIZATION, NUCLEAR)

H77 10272 HYDROGEN ENERGY TECHNOLOGY - UPDATE 1976

Pangborn, J.B., Gregory, D.P., (Energy Systems Research, Institute of Gas Technology, Chicago, IL), International Journal of Hydrogen Energy, V 1:331-340, N3, 1976

Hydrogen, a chemical commodity and fuel now produced from natural gas, could, in the future, become a widely used fuel produced from water and diverse energy sources. Since the initial flurry of interest in "hydrogen economy" concepts, serious feasibility studies, technology assessments, and experimental studies have identified economic and technological problem areas. Production now appears to be the focus of most hydrogen research and development efforts as shown by a review of the technical papers presented at the First World Hydrogen Energy Conference. Specific industrial uses, electric power storage, and perhaps additions of hydrogen to supplement the natural gas supply appear to be near-term prospects for hydrogen utilization.

(RESEARCH, DEVELOPMENT, FUEL)

H77 10273 TECHNOLOGIES TODAY AND TOMORROW

Ohta, T., (Faculty of Engineering, Yokohama National University, Yokohama, Japan), International Journal of Hydrogen Energy, V 1:241-243, N2, 1976

Given that it is necessary for science and technology to produce or synthesize energy-forms and refine materials freely, the question is how to accomplish this using replenishable, widely available resources such as sunshine, water, air and soil. This is the new callenge. Technologies which contribute to meeting this objective could be named "Resource-Leveling" technologies. This signifies the fact that resources are to be employed which are not normally thought of as being resources in many instances, and which do not suffer the maldistribution characteristics, say of oil.

(ENERGY, RESOURCE, WATER)

H77 10274 FOSSIL/HYDROGEN ENERGY MIX AND POPULATION CONTROL

Veziroglu, T.N., Kakac, S., Basar, O., Forouzanmehr, N., (University of Miami, Coral Gables, FL), International Journal of Hydrogen Energy, V 1:205-217, N2, 1976

An energy system based on fossil fuels and synthetic hydrogen fuel, mixed at various ratios, has been considered as a function of some population growth controls. The results indicate that the increased use of hydrogen and slowing down the population growth would have beneficial effects on various world parameters such as pollution, resource conservation and the quality of life.

(SYSTEM, FUEL, POLLUTION)

H77 10275 HYDROGEN ENERGY SYSTEMS TECHNOLOGY STUDY

Kelley, J.H., (Jet Propulsion Laboratory, Pasadena, CA), International Journal of Hydrogen Energy, V 1:199-204, N2, 1976

The National Aeronautics and Space Administration (NASA) Office of Energy Programs initiated the Hydrogen Energy Systems Technology (HEST) Study in the autumn of 1974. The Caltech Jet Propulsion Laboratory (JPL) was made responsible for conducting the study and reporting the results, with acive support from several NASA Centres through a Working Panel. Objectives of the study were defined to be the assessment of national needs for hydrogen, based on current uses and visible trends, and determination of the critical research and technology activities required to meet these needs, with attention to economic, social, and environmental considerations, providing a basis for the planning of a hydrogen research and technology program.

(RESEARCH, TECHNOLOGY, ENVIRONMENT)

H77 10276 HYDROGEN-OXYGEN UTILIZATION SYSTEMS

Escher, W.J.D., (Escher Technology Associates, St. Johns, MI), International Journal of Hydrogen Energy, V 1:189-198, N2, 1976

A Hydrogen-energy system embracing production, delivery and utilization or end-use means, can alternatively take on one of two basic configurations: (1) hydrogen (only) or (2) hydrogen + oxygen. The former, which would be analagous to today's natural gas system, implies air-using utilization devices in which the oxygen required for sustaining the using-point energy conversion by way of heat-release or electricity-generation, is extracted from the atmosphere.

(PRODUCTION, UTILIZATION, NATURAL GAS)

H77 10277 THE ROLE OF HYDROGEN IN THE ENERGY FUTURE OF THE UNITED STATES

Gregory, D.P., (Institute of Gas Technology, Chicago, IL), International Journal of Hydrogen Energy, V 1:109-112, N2, 1976

It is commonly believed that to sustain a healthy economic growth, the use of energy in the U.S. must also continue to grow. When we look at the alarming decline in the availability of oil and gas, we can clearly see that a major shift must be made toward other energy sources - nuclear, solar and coal being the most abundant and important - if the U.S. is going to have the energy to continue this growth. The use of conventional technology stresses the conversion of these energy forms into electricity for delivery to the customer. Because electricity is not readily storable, is expensive to transmit and is not immediately useful in the vast majority of industrial and domestic energy-consuming equipment, the alternative course of converting these abundant energy sources to a chemical fuel that is more compatible with today's energy distribution and utilization equipment has merit.

(NUCLEAR, SOLAR, COAL)

H77 10278 HYDROGEN ENERGY

Gregory, D.P., Pangborn, J.B. (Institute of Gas Technology, Chicago, IL), Annual review of Energy, V 1:279, March 1976

As this country's energy supply moves toward a system based on nonfossil sources, we must consider how these new energy sources can best be delivered to the customer. Nuclear technology is currently used to provide electric power, and most research and development applied to the bulk conversion of energy from solar, geothermal, wind, tide, and biological sources is also associated with electric power. In the future, nonfossil energy sources must be used in vastly increased amounts, for this is the only way to provide the United States with an adequate energy supply not dependent upon imports that will be politically and economically detrimental during the twenty-first century.

(SUPPLY, FOSSIL FUEL, NUCLEAR, CONVERSION)

II. PRODUCTION

H77 20566 HYDROGEN PRODUCING CYCLES USING ELECTRICITY AND HEAT - HYDROGEN HALIDE CYCLES: ELECTROLYSIS OF HBr

Schuetz, G.H., (Joint Research Centre of the European Communities Ispra Establishment, (Va.), Italy), International Journal of Hydrogen Energy, V 1:379-388, N4, 1977

An alternative to water electrolysis or thermochemical water splitting for hydrogen production could be a process using both electricity and heat. The electrolysis of hydrogen halides may be an important step of such hybrid processes. Some preliminary results obtained by electrolyzing concentrated hydrobromic acid with different electrode materials and at different temperatures are presented. High current densities were obtained at 1 V and less with electrodes of noble metals at low bromine concentrations.

(ELECTROLYSIS, THERMOCHEMICAL, ELECTRICITY)

H77 20567 COMPETITIVELY PRICED HYDROGEN VIA HIGH-EFFICIENCY NUCLEAR ELECTROLYSIS

Escher, W.J.D., Donakowski, T.D., (Institute of Gas Technology, Chicago, IL), International Journal of Hydrogen Energy, V 1:389-399, N4, 1977

A fully dedicated nuclear-electrolytic hydrogen-production facility, based on advanced (1985) technology, has been synthesized and assessed at the conceptual level. The facility integrates 1) an HTGR operating a binary shaftpower-extraction cycle at 980°C (1800 F) top temperature, 2) direct d.c. electricity generation via acyclic generators, and 3) high-current density, high-pressure electrolyzers based on the solid polymer electrolyte approach. All subsystems are close-coupled and optimally interfaced. Pipeline-pressure hydrogen and coproduct oxygen are produced at 6900kPa (1000 psi). On consistent costing bases, the advanced facility concept was found to provide hydrogen costs that were approximately half those associated with conventional, contemporary-technology nuclear electrolysis. Representative costs were $4.81/GJ ($5.07/million Btu) vs $9.36/GJ ($9.88/million Btu). The nuclear heat-to-hydrogen energy conversion efficiency for the advances system was estimated as 43%, vs 25% for the baseline present-day approach.

(NUCLEAR, ELECTROLYSIS, COST)

H77 21123 THE THERMOCHEMICAL HYDROGEN PROGRAM AT N.C.L.I.

Kotera, Y., (National Chemical Laboratory for Industry, Meguro Tokyo, Japan), International Journal of Hydrogen Energy, V 1:219-220, N2, 1976

This short communication describes work now underway at the National Chemical Laboratory for Industry (N.C.L.I.) in Tokyo, Japan on the production of hydrogen from H2S or H2O by thermochemical processes. Emphasis is placed on the chemistry of the processes and the use of catalysts in various reactions.

(CYCLE, CATALYST, PRODUCTION)

H77 21124 STAGE EFFICIENCY IN THE ANALYSIS OF THERMOCHEMICAL WATER DECOMPOSITION PROCESSES

Conger, W.L., Funk, J.E., Carty, R.H., Soliman, M.A., Cox, K.E., (The College of Engineering, The University of Kentucky, Lexington, KY), International Journal of Hydrogen Energy, V 1:245-250, N2, 1976

The procedure for analyzing thermochemical water-splitting processes using the figure of merit is expanded to include individual stage efficiencies, n_j, and loss coefficients, Ξ_j, The use of these quantities to establish the thermodynamic inefficiencies of each stage is shown. A number of processes are used to illustrate these concepts and procedures and to demonstrate the facility with which process steps contributing most to the cycle efficiency are found. The procedure allows attention to be directed to those steps of the process where the greatest increase in total cycle efficiency can be obtained.

(CYCLE, EFFICIENCY, THERMOCHEMICAL)

H77 21125 EFFICIENCY OF THERMOCHEMICAL PRODUCTION OF HYDROGEN

Fueki, K., (Department of Synthetic Chemistry, Faculty of Engineering, University of Tokyo, Tokyo, Japan), International Journal of Hydrogen Energy, V 1:129-131, N2, 1976

The overall thermal efficiency of several processes in the chemical industry is calculated from production units. The individual efficiency of a step was found to be 80% or less. Assuming an average thermal efficiency for each step to be 70%, the overall efficiency of two-, three- and four-step processes are estimated to be 50, 35 and 25%, respectively. Extrapolation of these results to the thermochemical decomposition of water leads to the conclusion that the process must consist of three steps or less in order for its efficiency to exceed that of electrolysis.

(CYCLE, EFFICIENCY, ELECTROLYSIS)

H77 21126 A COMPUTER-AIDED SEARCH PROCEDURE FOR THERMOCHEMICAL WATER-DECOMPOSITION PROCESSES

Yoshida, K., Kameyama, H., Toguchi, K., (Department of Chemical Engineering University of Tokyo, Tokyo, Japan), International Journal of Hydrogen Energy, V 1:123-127, N2, 1976

A systematic computer-aided method has been developed to search for closed thermochemical water-splitting cycles which utilize the high temperature heat from a nuclear reactor. This computer program is described and representative results are presented.

(CYCLE, COMPUTER, TEMPERATURE)

H77 21127 HYBRID CYCLE WITH ELECTROLYSIS USING Cu-Cl SYSTEM

Dokiya, M., Kotera, Y., (National Chemical Laboratory for Industry, Tokyo, Japan), International Journal of Hydrogen Energy, V 1:117-121, N2, 1976

A hybrid thermochemical-electrolysis water splitting cycle is proposed and preliminary experimental results are presented. The electrolytic step of the cycle consists of the cathodic reduction of hydrochloric acid and the anodic oxidation of Cu^{+} to Cu^{2+}. The cycle is closed by the reaction of $CuCl_2$ with steam at a temperature above 600°C to produce O_2, CuCl and HCl.

(CYCLE, ELECTROLYSIS, COPPER)

H77 21128 HYDROGEN PRODUCTION VIA THERMOCHEMICAL CYCLES BASED ON SULFUR CHEMISTRY

Soliman, M.A., Conger, W.L., Carty, R.H., Funk, J.E., Cox, K.E., (College of Engineering, The University of Kentucky, Lexington, KY), International Journal of Hydrogen Energy, V 1:265-270, N2, 1976

A class of closed thermochemical cycles for hydrogen production based on sulfur chemistry is presented. This class is described by the following set of chemical reactions:

$M + H_2O = MO + H_2$	(low temperature)
$MO + 0.5S = M + 0.5SO_2$	(high temperature)
$M'O + 1.5SO_2 = M'SO_4 + .5S$	(low temperature)
$M'SO_4 = M'O + SO_2 + 0.5O_2$	(high temperature)

Experimental investigation of some of the reactions is presented. Thermodynamic analysis indicates efficiencies of the range of 40-50% and sometimes higher. Not all of the reactions in the proposed cycles have been verified in the literature or through experimentation.

(CYCLE, SULFUR, THERMODYNAMICS)

H77 21129 THE REDUCTION OF HYDROGEN BROMIDE USING TRANSITION METAL COMPOUNDS

Mason, C.F.V., (Los Alamos Scientific Laboratory, University of California, Los Alamos, NM), International Journal of Hydrogen Energy, V 1:427-434, N4, 1977

Ways of accelerating the redox reaction between chromous bromide and hydrogen bromide to form chromic bromide and hydrogen are examined at room temperature. The process, although thermodynamically favorable, is extremely slow kinetically. Marked increases in rate have been obtained by using the hydrate, pyridine and dipyridyl complexes of chromium. In conjunction with catalysts, hydrogen yields of up to 71% in 10 min have been obtained. The significance of these results is discussed in the framework of closed thermochemical cycles for preparing hydrogen.

(REACTION, BROMINE, CYCLE, KINETICS)

H77 22029 HYDROGEN RICH GAS GENERATOR Patent

Houseman, J., Rupe, J.H., Kushida, R.O., (NASA, Pasadena Office, CA), 11 p., Issued May 11, 1976, Filed Feb 1975, Continuation-in-part of abandoned US Patent Appl.

SN-390049, Filed Aug 20, 1973, Sponsored by NASA

A process and apparatus is described for producing a hydrogen rich gas by injecting air and hydrocarbon fuel at one end of a cylindrically shaped chamber to form a mixture and igniting the mixture to provide hot combustion gases by partial oxidation of the hydrocarbon fuel. The combustion gases move away from the ignition region to another region where water is injected to be turned into steam by the hot combustion gases. The steam which is formed mixes with the hot gases to yield a uniform hot gas whereby a steam reforming reaction with the hydrocarbon fuel takes place to produce a hydrogen rich gas.

(GAS, HYDROCARBON, COAL)

H77 22030 THE THERMAL EFFICIENCY AND COST OF PRODUCING HYDROGEN AND OTHER SYNTHETIC AIRCRAFT FUELS FROM COAL

Witcofski, R.D., (NASA Langley Research Center, Hampton, VA), International Journal of Hydrogen Energy, V 1:365-377, N4, 1977

A comparison is made of the cost and thermal efficiency of producing liquid hydrogen, liquid methane and synthetic aviation kerosene from coal. These results are combined with estimates of the cost and energy losses associated with transporting, storing, and transferring the fuels to aircraft. The results of hydrogen-fueled and kerosene-fueled aircraft performance studies are utilized to compare the economic viability and efficiency of coal resource utilization of synthetic aviation fuels.

(COST, EFFICIENCY, COAL, AIRCRAFT)

H77 22031 APPARATUS FOR HYDROGEN PRODUCTION

Shalit, H., Hill, D., (Pa., assignor to Atlantic Richfield Company, Philadelphia, PA), Original application Mar 17, 1969, Ser. No. 807,864, now Patent No. 3,580,823, Divided and this application Jan 11, 1971, Ser. No. 105,617

An improved process and apparatus for the production of hydrogen of high purity whereby a carbonaceous fuel is reformed to produce hydrogen and said hydrogen is recovered economically from said reforming operation through the use of an electrolytic process using chemical energy of the reforming process to reduce electrical energy needed and in a molten electrolyte environment.

(CARBON, COAL, REFORMING)

H77 23034 METHANOL SEEN AS HYDROGEN SOURCE

Jonchere, J.P., Oil Gas J., V 74:71-73, N24, June 1976

Most-promising future use for methanol is as a source of hydrogen, more generally, synthesis gas. Both are easily produced from methanol. Forecasts of the hydrogen market have a high rate of growth linked to several large uses. These are increased desulfurization of petroleum products, cracking of vacuum gas oil, hydrogenation of coal, direct reduction of ores, or shaft injection into blast furnaces.

(METHANOL, SYNTHESIS GAS, COAL)

H77 23629 SOLAR HYDROGEN GENERATOR

Sebacher, D.I., Sabol, A.P., (NASA, Langley), NASA-CASE-LAR-11361-1, 11 p., Filed Mar 24, 1976, PAT-APPL-669 923/WE, N76-19564/3, This Government-owned invention available for U.S. licensing and, possibly, for foreign licensing

Avail:NTIS PC$3.50/MF$2.25

An apparatus is disclosed for using solar energy to decompose water molecules into hydrogen and oxygen molecules. Solar energy is concentrated on a globe containing water thereby heating the water to its dissociation temperature. The globe is pervious to hydrogen molecules permitting them to pass through the globe while being essentially empervious to oxygen molecules. The hydrogen molecules are collected after passing through the globe and the oxygen molecules are removed from the globe.

(SOLAR, WATER, TEMPERATURE)

H77 23630 PHOTOCHEMICAL AND THERMOELECTRIC UTILIZATION OF SOLAR ENERGY IN A HYBRID WATER-SPLITTING SYSTEM

Ohta, T., Asakura, S., Yamaguchi, M., Kamiya, N., Gotoh, N., Otagawa, T., (Hydrogen Energy Research Laboratories, Yokohama National University, Yokohama, Japan), International Journal of Hydrogen Energy, V 1:113-116, N2, 1976

A hybrid thermochemical water-splitting cycle using solar energy is proposed and experimental results are presented. The cycle consists of a photochemical reaction conducted in a flat cell with a Fresnel lens and concentrating the remaining solar energy on a thermoelectric generator which produces electric power for the electrolysis step. The overall efficiency is estimated to be as high as 15-25%.

(SOLAR, CYCLE, ELECTROLYSIS, PHOTOCHEMICAL)

H77 23631 HYDROGEN PRODUCTION USING SOLAR RADIATION

Ohta, T., (Yokohama National University, Yokohama, Japan), Veziroglu, T.N., (University of Miami, Coral Gables, FL), International Journal of Hydrogen Energy, V 1:255-263, N2, 1976

Various water-splitting methods using solar energy are reviewed and compared to each other. Direct thermal method has the highest efficiency, however it poses difficulties because of the need for heat-resisting materials. Thermochemical method becomes promising if corrosion-resisting materials are found. Electrolytic method is straightforward and conventional. However, a hybrid system combining electrolytic method with thermochemical and/or photochemical methods looks promising and is believed to result in optimum conversion efficiencies in the near future. Photolysis and biochemical methods are environmentally most acceptable, but are of low conversion efficiencies presently.

(SOLAR, EFFICIENCY, PHOTOCHEMICAL)

H77 23632 CONVERTING SOLAR ENERGY TO HYDROGEN: ANSWER TO U.S.'S LONG-RANGE ENERGY NEEDS?

Garyet, D., (University of Colorado, Boulder, CO), Civil Engineering - ASCE, 63 p., Jan 1976

Looking to the year 2000, a hydrogen economy may offer an attractive option to nuclear power. Hydrogen could fuel electric power plants, home furnaces, stoves and even automobiles.

(SOLAR, NUCLEAR, ENERGY SOURCE)

III. UTILIZATION

H77 31044 VULNERABILITY OF ADVANCED AIRCRAFT FUEL TO BALLISTIC AND SIMULATED LIGHTNING THREATS

Lippert, J.R., (Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, OH), International Journal of Hydrogen Energy, V 1:321-330, N3, 1976

The Advanced Fuel Vulnerability program is aimed at assessing relative vulnerability and identifying hazards associated with advanced (all but natural petroleum) fuels to determine their feasibility for use in military aircraft. Although primarily concerned with military aircraft, these hazards would also apply in limited degree to commercial aircraft. The initial advanced fuel selected for testing was Liquid Hydrogen (LH2). In addition to assessing it as a candidate petroleum fuel alternate, these tests with LH2 (the coldest fuel under consideration) could reveal problems associated with a cryogenic fuel. Initial survey tests reported herein compared the response of confined LH2 and JP-4 to ballistic impacts and lightning strikes. The reaction of LH2 results in less severe hydraulic ram and reduced fire. The responses of LH2 to lightning strikes indicate that strikes through vented gas external to the structure does not pose a serious problem. However, the internal arcing effect is a more complicated phenomenon and requires further investigation.

(AIRCRAFT, FUEL, SAFETY)

H77 32071 WATER INDUCTION IN HYDROGEN-POWERED IC ENGINES

Woolley, R.L., Henriksen, D.L., (Billings Energy Research Corporation, Provo, UT), International Journal of Hydrogen Energy, V 1:401-412, N4, 1977

Addition of water to the hydrogen-air mixture in the intake manifold is an effective means of both suppressing the tendency to backflash and reducing the production of oxides of nitrogen. Tests are run on a Dodge 440 CID V8 engine having a compression ratio of 12:1. Dramatic reduction in oxides of nitrogen is observed as the water flow is increased, yet essentially no change is observed in either power or efficiency. Exhaust temperature, NOx, and equivalence ratio is measured at each exhaust valve. It is found that a large cylinder to cylinder variation in NOx production is caused by slight non-uniformity in mixing of the hydrogen-air streams. It is further shown that NOx production is an exponential function of equivalence ratio, water to hydrogen mass ratio, and engine speed.

(FUEL, IC ENGINE, POLLUTION)

H77 32072 PERFORMANCE AND EMISSIONS OF HYDROGEN FUELED INTERNAL COMBUSTION ENGINES

De Boer, P.C.T., McLean, W.J., Homan, H.S., (Cornell University Ithaca, NY), International Journal of Hydrogen Energy, V 1:153-172, N2, 1976

A description is given of the differences between hydrogen engines and engines running on hydrocarbon fuels. The remarkable properties of hydrogen provide the potential of high thermal efficiency at part load, by operating the engine unthrottled with lean mixtures. They also are the cause of pre-ignition and backfiring problems. The latter problems can be solved in a number of ways, among which are the use of direct cylinder fuel injection, of lean mixtures, or of low compression ratios. Direct cylinder injection has the additional advantage of providing a high maximum power output. A detailed discussion is given of the thermal efficiency of hydrogen engines. Also discussed are phenomena leading to irregular engine operation such as surface ignition and spark knock. A detailed analysis is given of NO production. For lean mixtures the NO emissions are limited by the rate of formation, and for rich mixtures by the rate of decomposition during the expansion process. NO emissions are negligibly small for fuel-air equivalence ratios below about 0.55. Peak NO emissions occur at equivalence ratios near 0.8, and are of the same order as for gasoline engines. It is concluded that the hydrogen engine is a practical possibility, likely to find a number of applications within the next few decades.

(IC ENGINE, POLLUTION, FUEL)

IV. TRANSMISSION, DISTRIBUTION, AND STORAGE

H77 40432 A NEW HYDROGEN STORAGE ELECTRODE

Bronoel, G., Sarradin, J., Bonnemay, M., (Laboratoire d'Electrolyse du CNRS, France), Percheron, A., Achard, J.C., Schlapbach, L., (Laboratoire des Terres Rares Du CNRS, France), International Journal of Hydrogen Energy, V 1:251-254, N2, 1976

This paper presents experimental evidence that it is possible to use a cathodic charge to store hydrogen on compounds such as LaNi5. Using an alkaline medium (KOH 5N) in an unpressurized system at 20°C, the mass capacity was found to be approximately 330 mAH/g (5H/mol LaNi5). Comparison of these results with the solid-gas isotherms indicated that the hydrogen is held in a non-equilibrium state. The influence of temperature, stoichiometry and substitution in the LaNi5 on the capacity are presented.

(CATHODE, LANTHANUM, ELECTRODE)

H77 40616 ECONOMICS OF CRYOCABLES

Voth, R.O., Hord, J., (Cryogenics Division, Institute for Basic Standards, National Bureau of Standards, Boulder, CO), International Journal of Hydrogen Energy, V 1:271-289, N2, 1976

This paper examines the technical and economic feasibilities of: (1) using cryogenic hydrogen to cool a.c. cryoresistive or d.c. superconducting power transmission cables and, (2) delivering liquid hydrogen concurrently with cryoresistive or superconducting electrical power through a common cable. Cryogenic hydrogen coolant options considered are subcooled liquid and slush. Cryogenic nitrogen and helium coolants are also considered for cryoresistive and superconducting cables, respectively, to provide reference data for comparison with our H2-coolant calculations. Thermodynamic analyses are performed to optimize the coolant flow rate and refrigerator spacing for each specific coolant, coolant fluid state, cable design, cable insulation quality and energy delivery option. The use of hydrogen as a coolant in electrical cables is discussed from a safety viewpoint. Helium-cooled and hydrogen-cooled superconducting power transmission lines are shown to be economically competitive and offer lower unit-transmission costs than conventional underground power lines. The hybrid hydrogen-superconducting cable concurrently transmits liquid hydrogen and electricity at the lowest unit cost of all cryocable energy systems examined. Hydrogen-cooled power lines and hybrid hydrogen-electric energy cables appear to be technically and economically feasible; however, they do not currently provide sufficient economic incentive to warrant the increased hazard of operation.

(ECONOMICS, CRYOGENIC, HELIUM)

H77 40617 NASA SPACE PROGRAM EXPERIENCE IN HYDROGEN TRANSPORTATION AND HANDLING

Bain, A.L., (NASA, SO-ENG-2 Kennedy Space Center, FL), International Journal of Hydrogen Energy, V 1, N2, 1976

This paper portrays the experience gained in the transportation and handling of hydrogen in support of the Apollo launch site at Kennedy Space Center (KSC), FL, one of NASA's prime hydrogen users in the Space Program. The objective of the paper is basically to reveal the types of systems involved in handling hydrogen, safety practices, operational techniques, other general experience information, and primarily to convey the routinism by which this potential fuel of the future has already been handled in significant quantities for a number of years.

(TRANSPORTATION, SAFETY, SYSTEM)

H77 43070 NMR STUDIES OF STRUCTURE AND DIFFUSION IN METAL HYDRIDES

Bowman, R.C., Jr., Attalla, A., Tadlock, W.E., (Monsanto Research Corporation, Miamisburg, OH), International Journal of Hydrogen Energy, V 1:421-426, N4, 1977

Various pulse nuclear magnetic resonance (NMR) techniques have been used to determine the proton lineshapes and nuclear relaxation times in metal hydrides. Analysis of the NMR data provide information on the nature of the lattice sites occupied by protons and on the hydrogen diffusion parameters. The effects of hydrogen concentration and temperature on hydrogen diffusion in vanadium hydride has been investigated. NMR measurements have also been performed on the two iron-titanium (FeTi) hydride phases. The implications of NMR studies on the general behavior of metal hydrides as hydrogen storage materials is briefly discussed.

(NMR, HYDRIDE, TITANIUM, STORAGE)

H77 43071 PHYSICAL METALLURGY OF FeTi-HYDRIDE AND ITS BEHAVIOUR IN A HYDROGEN STORAGE CONTAINER

Pick, M.A., Wenzl, H., (Institut für Festkörperforschung, Kernforschungsanlage Jülich, West Germany), International Journal of Hydrogen Energy, V 1:413-420, N4, 1977

FeTi-samples have been prepared and characterized by metallography, X-ray diffraction, neutron diffraction and specific heat measurements. The conditions for the presence of the ordered CsCl structure at room temperature have been investigated. This material has been used to study FeTi-hydrides, especially the structure, phase transition and the heat of reaction as a function of the hydrogen concentration. The heat of reaction is 30 kJ/mole H2 for $0.05<c<0.5$ (c = atomic ratio: atoms H/atoms metal). The heat of solution ($c \to 0$) is approx. 130 kJ/mole H2. The FeTi material has been used to build and operate a small hydrogen storage container (1 Nm^3H2) as an alternative to high pressure hydrogen gas containers in the laboratory.

(IRON, TITANIUM, HYDRIDE)

H77 43072 METAL HYDRIDE STORAGE FOR MOBILE AND STATIONARY APPLICATIONS

Hoffman, K.C., Reilly, J.J., Salzano, F.J., Waide, C.H., Wiswall, R.H., Winsche, W.E., (Brookhaven National Laboratory, Upton, NY), International Journal of Hydrogen Energy, V 1, N2, 1976

Metal hydrides offer the possibility of a convenient and safe method for the storage of hydrogen. These compounds provide for compact storage in a form that is equal to or better than cryogenic liquid hydrogen on a volume basis. Considerable research has gone into the study of hydrides derived from rare earth, iron-titanium and magnesium alloys. The formation of these compounds is reversible and the chemistry of relevant hydrides has been discussed. Heat must be provided to decompose these compounds and release the hydrogen, while heat is liberated when the compounds are formed and must be removed to allow the hydriding reactions to proceed to completion. The iron-titanium and magnesium alloys are especially promising hydride storage media, the former in stationary applications, or where weight is not a limiting consideration, and the latter for mobile applications. Each of these materials has unique pressure-temperature characteristics and reaction kinetics which must be considered in the design of a hydrogen storage system. These special characteristics are discussed for particular applications. The results of recent work on hydrogen storage development and the engineering design of storage systems are reviewed.

(IRON, ALLOY, STORAGE, MAGNESIUM)

H77 43073 HYDROGEN STORAGE VIA IRON-TITANIUM FOR A 26 MW(e) PEAKING ELECTRIC PLANT

Beaufrere, A.H., Salzano, F.J., Isler, R.J., Yu, W.S., (Department of Applied Science, Brookhaven National Laboratory, Upton, NY), International Journal of Hydrogen Energy, V 1:303-319, N3, 1976

Work is in progress at the Brookhaven National Laboratory for the development of bulk storage techniques for hydrogen using iron-titanium. The program consists of a variety of activities which include engineering analysis and design of a large bulk hydrogen storage facility, engineering-scale tests, work on the selection and development of suitable iron-titanium alloys, and the construction of a large prototype energy storage system. Based on these engineering studies, a priliminary plant, with hydrogen production via water electrolysis, iron-titanium metal hydride hydrogen storage beds and hydrogen-air fuel cells for reconversion to electricity. Cost estimates of a similar plant incorporating advanced technology components are made and compared with allowed costs for such systems. Description of R & D requirements to achieve these goals is discussed.

(IRON, TITANIUM, ANALYSIS, STORAGE)

H77 43074 A HIGH-EFFICIENCY POWER CYCLE IN WHICH HYDROGEN IS COMPRESSED BY ABSORPTION IN METAL HYDRIDES

Powell, J.R., Salzano, F.J., Yu, W.S., Milau, J.S., (Brookhaven National Laboratory, Upton NY), Science, V 193:314, N4250, 1976

A high-efficiency power cycle is proposed in which molecular hydrogen gas is used as a working fluid in a regenerative closed Brayton cycle. The hydrogen gas is compressed by an absorption-desorption cycle on metal hydride ($FeTiH_x$) beds. Low-temperature solar or geothermal heat (temperature about 100°C) is used for the compression process, and high-temperature fossil fuel or nuclear heat (temperature about 700°C) supplies the expansion work in the turbine. Typically, about 90 percent of the high-temperature heat input is converted to electricity, while about 3 kilowatts of low-temperature heat is required per kilowatt of electrical output.

(CYCLE, ELECTRICITY, BRAYTON CYCLE)

H77 43075 HYDROGEN STORAGE BY BINARY AND TERNARY INTERMETALLICS FOR ENERGY APPLICATIONS - A REVIEW

Newkirk, H.W., Aug 1976, UCRL-52110

Binary and ternary intermetallic compounds are being considered as a possible solution to storage problems in the use of hydrogen as an alternative fuel for many applications. For selected systems, this report reviews and summarizes theories of storage optimization, experimental procedures, property data, potential applications for stationary and mobile energy storage, resource and economic analyses, and safety factors. The systems surveyed are those binary, ternary, and complex intermetallic compounds containing a member of the transition element series, a member of the rare earth series, and/or a member of the actinide series.

(INTERMETALLICS, STORAGE, SAFETY)

V. .SAFETY

H77 50026 IS HYDROGEN SAFE?

Hord, J., (National Bureau of Standards, Department of Commerce, Washington, DC), Oct 1976, NBS-TN-690

The safety aspects of hydrogen are systematically examined and compared with those of methane and gasoline. Physical and chemical property data for all three fuels are compiled and used to provide a basis for comparing the various safety features of the three fuels. Each fuel is examined to evaluate its fire hazard, fire damage, explosive hazard and explosive damage characteristics. The fire characteristics of hydrogen, methane and gasoline, while different, do not largely favor the preferred use of any one of the three fuels; however, the threat of fuel-air explosions in confined spaces is greatest for hydrogen.

(EXPLOSION, FIRE, FUEL, GASOLINE, HYDROGEN, METHANE, SAFETY)

H77 52159 HYDROGEN TRANSPORT AND EMBRITTLEMENT IN STRUCTURAL METALS

Louthan, M.R., Jr., Caskey, G.R., Jr., (Savannah River Laboratory, E.E. du Pont de Nemours & Co. Aiken, SC), International Journal of Hydrogen Energy, V 1:291-305, N3, 1976

The close relationship between hydrogen transport and embrittlement is indicated by evidence of hydrogen absorption preceding degradation of mechanical properties. Concentration of hydrogen at a crack or flaw by diffusion or by transport with moving dislocations is probably necessary also. Experimental studies show that hydrogen permeation is significantly influenced by surface conditions, particularly oxide films, and internal defects and impurities that trap diffusing hydrogen. The usual thermodynamic and diffusion relations, therefore, do not predict accurately the final distribution of hydrogen and the kinetics of the processes.

(EMBRITTLEMENT, ABSORPTION, DIFFUSION)

H77 52160 HYDROGEN PROBLEMS IN ENERGY RELATED TECHNOLOGY

Hirth, J.P., (Metallurgical Engineering Department, Ohio State University, Columbus, OH), Johnson, H.H., (Materials Science Center, Cornell University, NY), Corrosion - NACE, V 32, N1, 1976

A survey of hydrogen degradation problems in energy related systems is presented. Nine separate phenomenological classifications of such degradation are presented. Key areas of unsolved problems and needed research are specified. Hydrogen embrittlement mechanisms and hydrogen attack in particular, are pinpointed as crucial areas requiring study.

(ENERGY SYSTEM, CORROSION, MECHANISM)

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